Searching for sterile neutrinos and other beyond-SM physics at SBN

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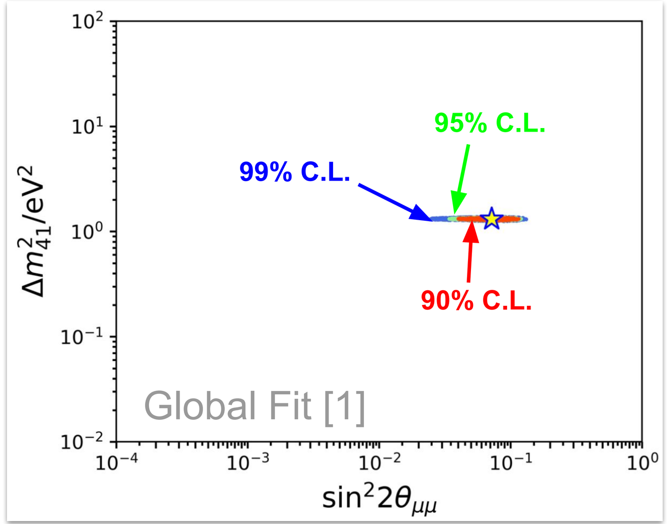
1. Short Baseline Anomalies and eV-scale Sterile Neutrinos

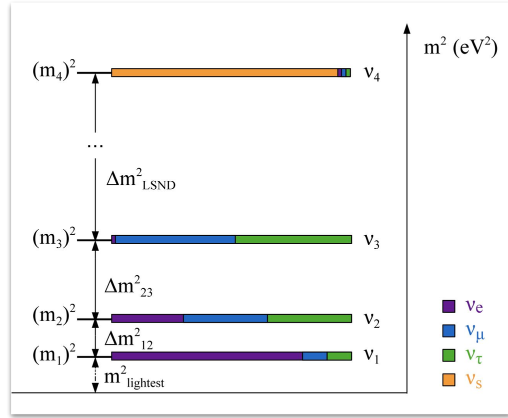
- Measurements of neutrino event rates at “short baselines” are inconsistent with the 3-ν picture
- Global fits (e.g. [1]) indicate that a neutrino oscillation interpretation of the anomalies requires neutrinos with Δm^2 ~ 1eV^2, and yet there is still tension between fits to appearance and disappearance data sets



- Neutrino oscillation probabilities for 3 active and 1 sterile neutrinos (3+1):

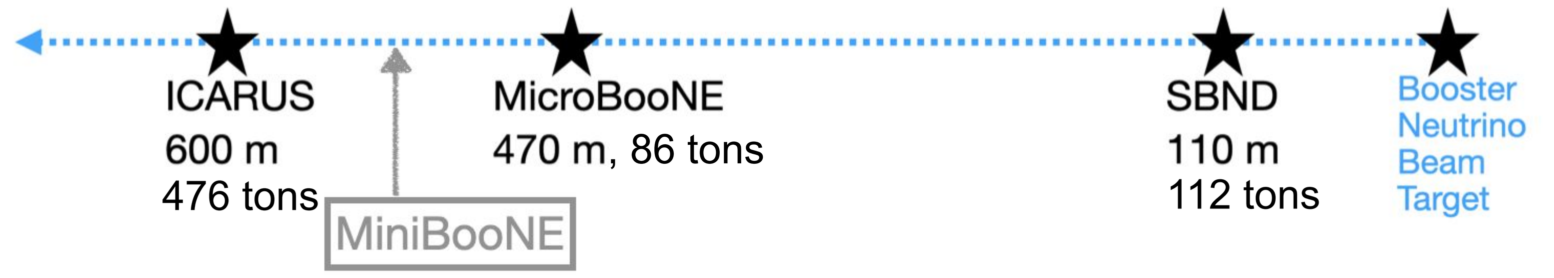
$$P(\nu_\mu \to \nu_e) = \sin^2(2\theta_{\mu e})\sin^2\left(\frac{1.27\Delta m^2_{41}L}{E}\right)$$

$$P(\nu_\mu \to \nu_\mu) = 1 - \sin^2(2\theta_{\mu\mu})\sin^2\left(\frac{1.27\Delta m^2_{41}L}{E}\right)$$



- Probability is maximized at L/E ~ 1m/MeV

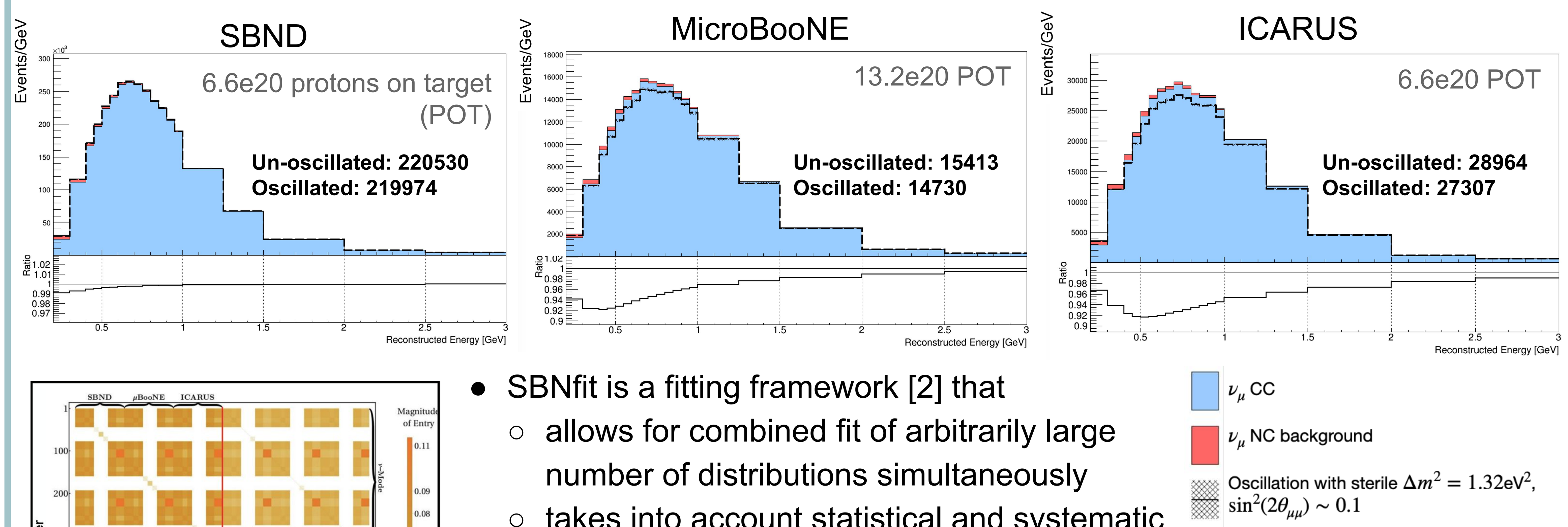
2. Short Baseline Neutrino Program (SBN)

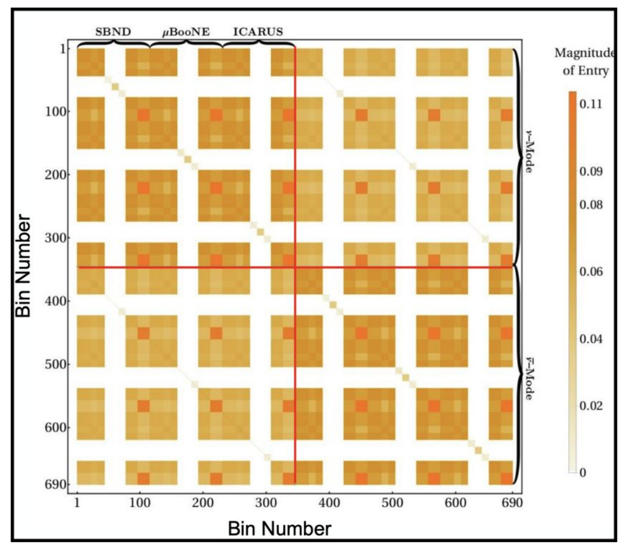


- SBN comprises three liquid argon (LArTPC) detectors downstream the Fermilab Booster Neutrino Beamline (BNB)
- MicroBooNE and ICARUS detectors satisfy L/E ~ 1m/MeV, so SBN is sensitive to sterile neutrino oscillations (for Δm^2 ~ 1eV^2)

3. SBNfit Framework

Simulated ν_μ spectrum at each SBN detector, with and without oscillations (disappearance):





Systematic covariance matrix including correlations

- SBNfit is a fitting framework [2] that
  - allows for combined fit of arbitrarily large number of distributions simultaneously
  - takes into account statistical and systematic uncertainties and systematic correlations between spectra by full covariance matrix and χ^2 test statistics
- Systematic uncertainties and correlations (flux and cross-section) between three detectors allows SBNfit to constrain oscillation parameters

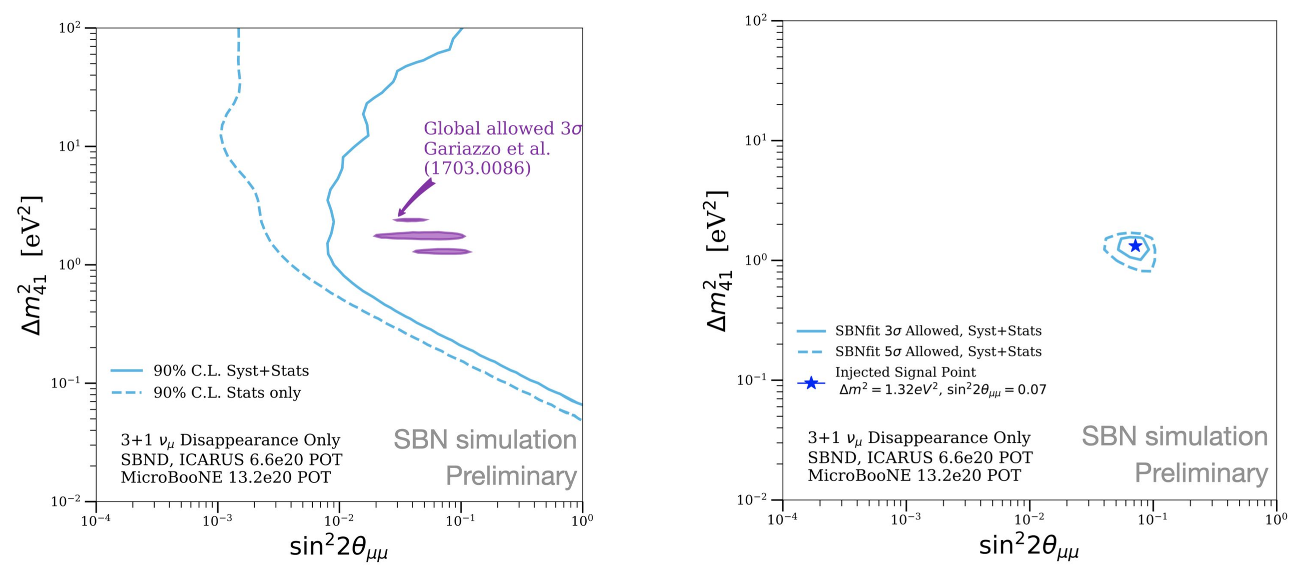
**The results shown in the poster employ the same systematic error assignments used in the SBN proposal [3] with known caveats. Work is currently in progress to improve the SBN oscillation sensitivity calculations by a) migrating to a better-motivated interaction model and modern uncertainty assignments from GENIE 3, b) incorporating a first evaluation of uncertainties in the detector response, and c) evaluating model dependencies and biases in the extrapolation from SBND to ICARUS*

4. SBN Sensitivity Study

ν_μ disappearance

Only fit to ν_μ spectra

Assume 3+1 model and negligible appearance



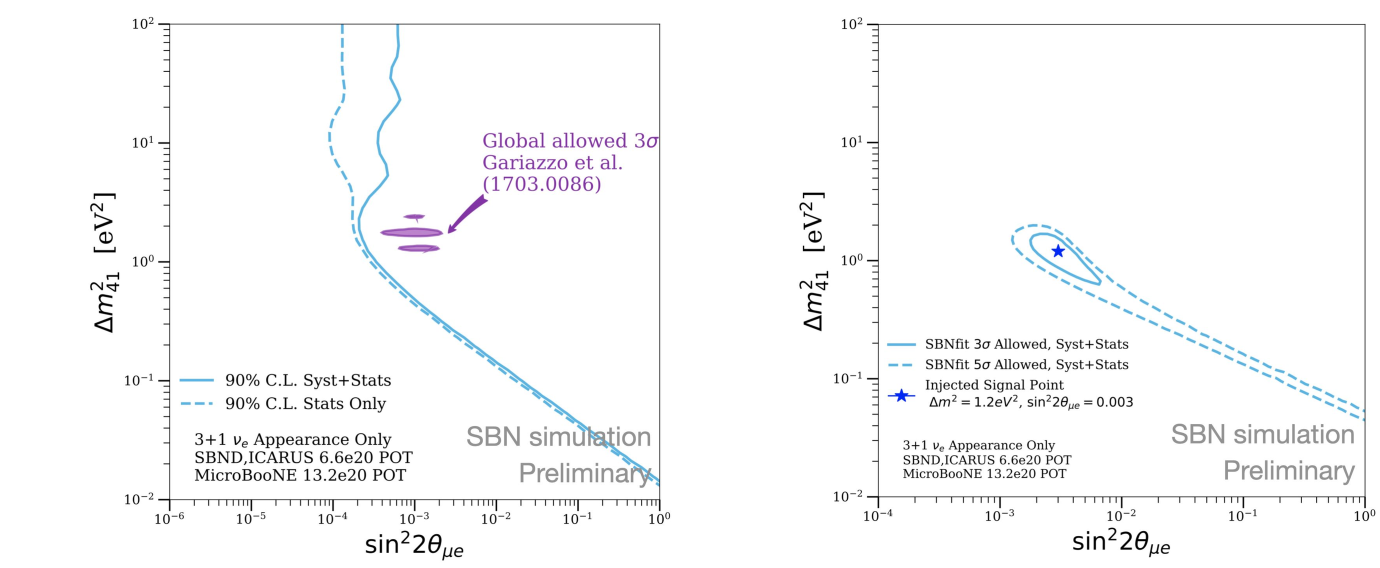
- **Sensitivity** curve assumes observation of central value prediction with no oscillation; simple raster scan used
- Allowed region plot assumes observation of signal with

$$\sin^2(2\theta_{\mu\mu}) = 0.07,\ \Delta m^2 = 1.32\mathrm{eV}^2$$

ν_e appearance

Only fit to ν_e spectra

Assume 3+1 model and negligible disappearance

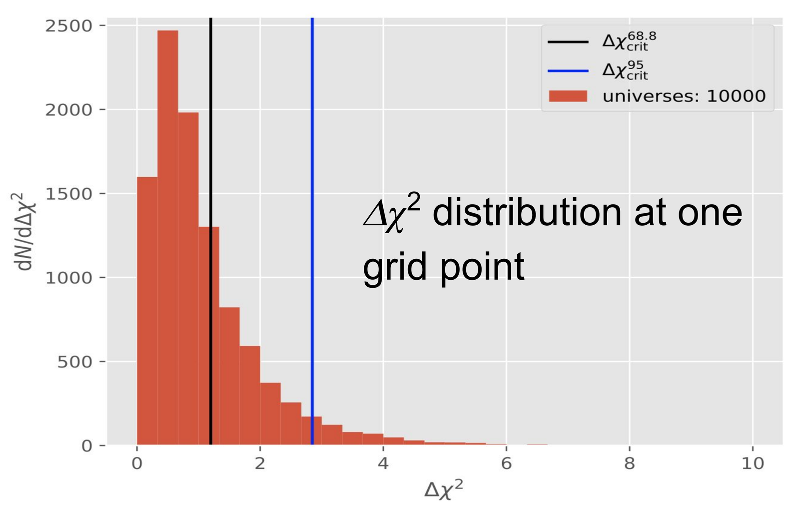


- **Sensitivity** curve assumes observation of central value prediction with no oscillation; simple raster scan used
- Allowed region plot assumes observation of signal with

$$\sin^2(2\theta_{\mu e}) = 0.003,\ \Delta m^2 = 1.2\mathrm{eV}^2$$

SBNfit also allows simultaneous ν_μ disappearance, intrinsic ν_e disappearance and ν_e appearance fit

5. SBNfit on High Performance Computing



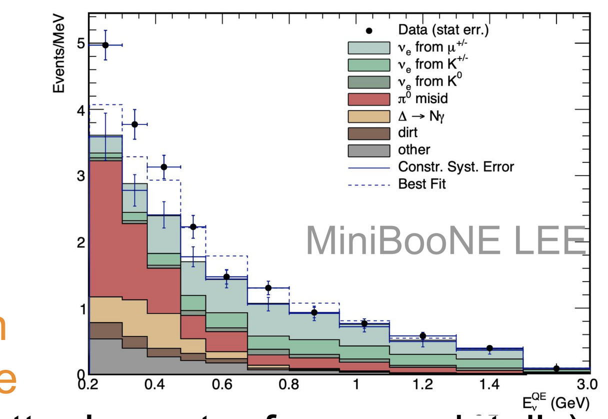
- A more precise way to extract the allowed/excluded regions is the frequentist method proposed by Feldman and Cousins [4], which requires quantifying statistical significance through “fake” experiments drawn from the prediction, within its associated uncertainty, with every set of oscillation parameters
- We have been working with SciDAC team at Fermi National Lab to port SBNfit onto High Performance Computing (HPC) cluster “Cori” at NERSC to take full advantage of HPC [5]

	$N_{\mathrm{univ}} = 10^4$ (3σ)	$N_{\mathrm{univ}} = 10^8$ (5σ)
Cori phase 1 (Haswell)	7.2×10^5	7.2×10^3
Cori phase 2 (KNL)	1.2×10^6	1.2×10^4

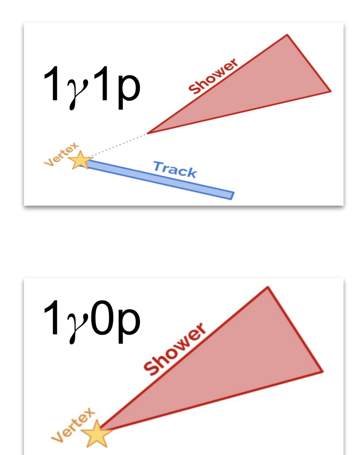
Max grid size for a full-day run on Cori

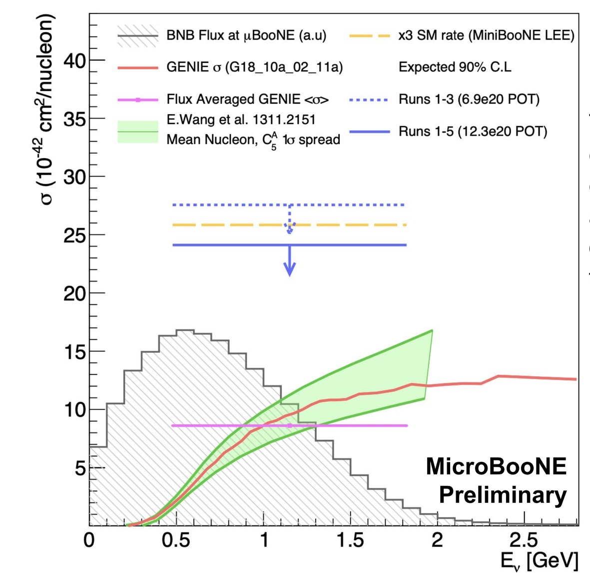
6. Other beyond-SM Physics at SBN

- The MiniBooNE low-energy excess (LEE) [6] is an anomalous short-baseline measurement which could also be interpreted as anomalous single photon production
- MicroBooNE [7] has developed an analysis to test this hypothesis assuming enhanced neutral-current (NC) resonant Δ production followed by Δ radiative decay (see Kathryn Sutton’s poster for more details)



For such model that is not L-dependent, SBND offers 17x higher statistics than MicroBooNE, and a highly sensitive rate measurement!





The expected classical 90% confidence intervals, assuming observation of data consistent with the SM prediction [7]

References:

[1] Diaz et al., Where are we with light sterile neutrinos?. 2019.

[2] Cianci et al., Prospects of Light Sterile Neutrino Oscillation and CP Violation Searches at the Fermilab Short Baseline Neutrino Facility. Phys. Rev. D, 96(5):055001, 2017.

[3] M. Antonello et al., A Proposal for a Three Detector Short-Baseline Neutrino Oscillation Program in the Fermilab Booster Neutrino Beam. 3 2015.

[4] Gary J. Feldman and Robert D. Cousins, Unified approach to the classical statistical analysis of small signals. Phys. Rev. D, 57(7):3873–3889, Apr 1998.

[5] Schulz et al., Grid-based minimization at scale: Feldman-cousins corrections for sbn. 02 2020.

[6] Aguilar-Arevalo et al., Significant excess of electronlike events in the miniboone short-baseline neutrino experiment. Phys. Rev. Lett. 121(22), Nov 2018.

[7] M. Collaboration, The MicroBooNE Single-Photon Low-Energy Excess Search, MicroBooNE public note 1087.

NEUTRINO 2020